

STAX. An Axion-like Particle Search with Microwave Photons

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We discuss an improved detection scheme for a light-shining-through-wall (LSW) experiment for axion-like particle searches. We propose to use: gyrotrons or klystrons, which can provide extremely intense photon fluxes at frequencies around 30 GHz; transition-edge-sensors (TES) single photon detectors in this frequency domain, with efficiency ≈ 1 ; high quality factor Fabry-Perot cavities in the microwave domain, both on the photon-axion conversion and photon regeneration sides. We compute that present laboratory exclusion limits on axion-like particles might be improved by at least four orders of magnitude for axion masses $\lesssim 0.02$ meV.

1 Introduction

Axions [1] are between the most serious dark matter candidates. They are light neutral scalar or pseudoscalar bosons, with mass $m_a \approx \mu\text{eV} - \text{meV}$, coupled to the electromagnetic field via

$$\mathcal{L}_I = \frac{1}{4} G a F^{\mu\nu} \tilde{F}_{\mu\nu} \quad (1)$$

In QCD axion models (DFSZ [2] and KSVZ [3]), the axion-photon coupling constant G is directly related to m_a ; thus, G is the only free parameter of the theory. In axion-like particle (ALP) searches, the parameter space is extended: G and m_a are the free parameters [4].

Axions and ALPs experimental searches can be divided into two main categories: 1) Axions from astrophysical and cosmological sources; 2) Laboratory searches. In the former case, exclusion limits on the axion-photon coupling constant are provided by estimates of stellar-energy losses [4, 5], helioscopes [6, 7, 8] and haloscopes [6, 9]. In the latter case, limits on G are given by photon polarization [10] and Light-Shining-Through-Wall (LSW) [6, 11, 12, 13, 14] experiments.

In this contribution, we will focus on LSW experiments. After a brief description of the standard LSW experimental apparatus, we will discuss how to improve present ALPs laboratory limits on G by at least four orders of magnitude [15]. We are willing to do this by using extremely intense photon fluxes from gyrotron sources at frequencies around 30 GHz, TES single photon detectors with efficiency ≈ 1 , and high quality factor Fabry-Perot cavities in the microwave domain ($Q \approx 10^4 - 10^5$), both on the photon-axion conversion and photon regeneration sides.

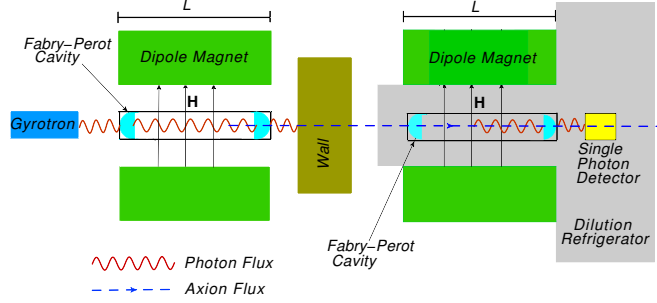


Figure 1: Experimental configuration of the STAX LSW experiment. Fig. from Ref. [15]; Elsevier B.V. copyright.

2 LSW experiments

In a LSW experiment [6, 11, 12, 13, 14], a coherent photon beam traverses an intense magnetic field, \mathbf{H} . Here, some photons can convert into axions via the Primakoff effect. Photons exchange 3-momentum \mathbf{q} with \mathbf{H} , the energy is conserved. If the \hat{x} axis is chosen in the direction of the propagating photon beam, then the external magnetic is assumed to be uniform in the volume $L_x L_y L_z = L_x S$.

The photons which do not convert into axions are stopped by an optical barrier, “the wall”. while axions can cross the wall, due to their negligible cross-section with ordinary matter. On the other side of the wall there is a second magnetic field, which can convert axions back to photons. Reconverted photons may be detected via a single-photon detector.

In the $\epsilon_\gamma \gg m_a$ limit, the photon to axion (axion to photon) conversion probability is given by [6]

$$P_{\gamma \rightarrow a} = P_{a \rightarrow \gamma} = G^2 H^2 \frac{\sin^2(q_x L_x/2)}{q_x^2} \frac{\epsilon_\gamma}{\sqrt{\epsilon_\gamma^2 - m_a^2}} \quad (2)$$

where ϵ_γ is the photon (axion) energy and m_a the axion mass. In the limit $\epsilon_\gamma \approx m_a$, which is relevant for the STAX experiment, the previous expression for the conversion probability has to be regulated [15]

$$P_{\gamma \rightarrow a} = P_{a \rightarrow \gamma} = G^2 H^2 \frac{\sin^2(q_x L_x/2)}{q_x^2} \frac{\epsilon_\gamma}{\frac{1}{L_x} + \sqrt{\epsilon_\gamma^2 - m_a^2}} \quad (3)$$

The photon-axion-photon rate reads

$$\frac{dN_\gamma}{dt} = \Phi_\gamma \eta P_{\gamma \rightarrow a}^2 \quad (4)$$

where Φ_γ [s^{-1}] is the initial photon flux and η the single-photon-detector efficiency. The rate can be increased by introducing a Fabry-Perot cavity in the magnetic field area before the wall by a factor of Q , which is the quality factor of the cavity. Moreover, as discussed in Ref. [16], the rate can be further increased with the addition of a second Fabry-Perot cavity in the magnetic field region beyond the wall. See Fig. 1.

3 STAX experimental configuration and calculated exclusion limits

The best laboratory limits for the axion-photon coupling constant have been provided by the ALPS Collaboration [11]. The second stage of ALPS, ALPS-II [13], will improve the previous limits mainly by increasing the magnetic field length as well as introducing a second cavity in the magnetic field region behind the wall. ALPS-II configuration is very similar to that of Fig. 1, but in this case the photon flux is provided by an optical laser.

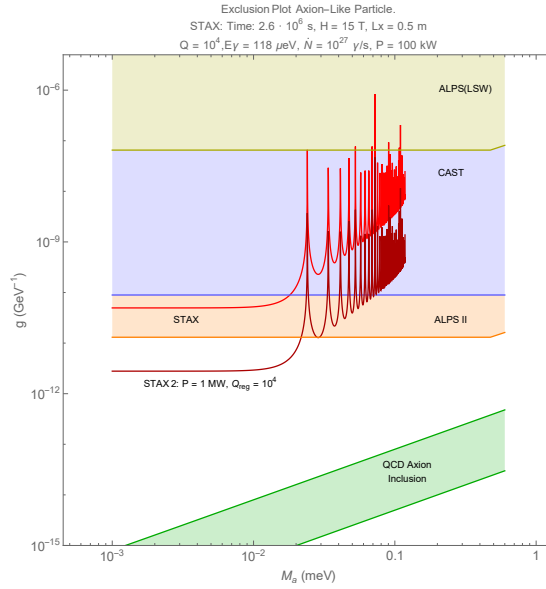


Figure 2: 90% CL exclusion limits that STAX and STAX 2 may achieve in case of a null result for axions with $m_a \lesssim 0.02$ meV. An exposure time of one month and zero dark counts are considered. “STAX” and “STAX 2” configurations correspond to a 100 kW and 1 MW gyrotron sources, respectively. Picture from Ref. [15]; Elsevier B.V. copyright.

Our goal is to develop a new generation LSW experiment and improve the limits on G by using sub-THz photon sources. Sub-THz sources, like gyrotrons and klystrons, can provide very high powers (up to 1 MW) at small photon frequencies, resulting in photon fluxes up to 10^{10} more intense than those from optical lasers, used in previous LSW experiments. We will also use high Q-factor Fabry-Perot cavities for microwave photons and single-photon detectors for light at these frequencies, with almost zero dark count, based on the (Transition-Edge-Sensor) TES technology. The TES detector will be coupled to an antenna and operated at temperatures ≈ 10 mK.

In this way, we computed that present laboratory exclusion limits on axion-like particles might be improved by at least four orders of magnitude for axion masses $\lesssim 0.02$ meV [15]. The limits that STAX experiment may achieve are compared to previous experimental results in Fig. 2.

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